SIMULATION OF POLYMER ALTERNATING GAS (PAG) FLOODING IN A SYNTHETIC HIGHLY PERMEABLE RESERVOIR MODEL

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ABSTRACT

Water alternating gas (WAG) or miscible CO_2-WAG injection has been a prevalent method to control mobility and enhance volumetric sweep efficiency for CO_2 flooding. Recent studies however show that most fields were unable to achieve the expected recovery factor from the WAG process, especially for high-permeability reservoirs. The effect of using polymer in water alternating gas injection (PAG) method as an enhanced oil recovery method in a synthetic sandstone reservoir model is investigated. The model of under investigation is a high permeable reservoir, so injected flood front would be breakthrough early times of injection periods. Hence, in the present work, a simulation study using reservoir simulator called STARS® commercialized by Computer Modelling Group Ltd. (CMG) was done to evaluate the potential benefit of adding polymer to the water during CO_2 WAG. The studies have shown that PAG flooding has recorded the lowest residual oil saturation (ROS) of 0.04 and the highest recovery factor (RF) of 56% compared to the water, CO_2 flooding, CO_2-WAG flooding and polymer flooding, implying PAG flooding have improved the sweep efficiency due to reduced the mobility ratio. The simulation results also showed a remarkable GOR reduction (at production well), a noticeable delay in the gas breakthrough, and an improvement in the areal sweep efficiencies during the PAG processes. Therefore, the synergy of polymer and CO_2-WAG flooding by taking advantage of polymer conformance control during water cycle and CO_2 miscibility with oil is said to have improved the microscopic displacement efficiency which is the paramount importance in the measurement of field's expected recovery, especially in a highly permeable reservoir.

ABSTRAK

Gas berselang-seling air (WAG) atau suntikan karbon dioksida-gas berselang-seli air (CO_2-WAG) yang terlarut merupakan kaedah lazim untuk mengawal mobiliti dan meningkatkan kecekapan isipadu sapu untuk banjir karbon dioksida CO_2. Kajian terbaru menunjukkan bahawa kebanyakan medan minyak tidak dapat mencapai faktor pemulihan minyak dijangka dari proses WAG, terutamanya reserbor yang mempunyai kebolehtelapan tinggi. Kesan menggunakan kaedah polimer dalam air suntikan gas (PAG) sebagai kaedah pemulihan minyak yang dipertingkatkan dalam model reserbor batu pasir sintetik telah disiasat. Model penyiasatan adalah reserbor resapan tinggi, jadi suntikan banjir akan mengalami terobosan semasa awal suntikan. Oleh itu, dalam siasatan ini, satu kajian simulasi menggunakan simulator reserbor yang dikenali sebagai STARS® dikomersialkan oleh Computer Modeling Group Ltd. (CMG) telah dijalankan untuk menilai potensi manfaat penambahan polimer ke dalam air semasa CO_2 WAG. Kajian telah menunjukkan bahawa banjir PAG telah mencatatkan ketepuan minyak sisa (ROS) paling rendah sebanyak 0.04 dan faktor pemulihan minyak tertinggi (RF) sebanyak 56% berbanding dengan banjir air, banjir CO_2, banjir CO_2-WAG dan banjir polimer, di mana banjir PAG dikatakan telah meningkatkan kecekapan isi padu sapu kerana nisbah mobiliti telah dikurangkan. Hasil simulasi juga menunjukkan pengurangan nisbah gas-minyak (GOR) yang luar biasa (di telaga pengeluar), kelewatan ketara dalam terobosan gas, dan peningkatan kecekapan sapuan kawasan semasa proses PAG. Oleh itu, sinergi banjir polimer dan CO_2-WAG dengan menggunakan kelebihan daripada kawalan pematuhan polimer semasa kitaran air dan keterlarutcampuran karbon diokida CO_2 dengan minyak dikatakan telah meningkatkan kecekapan anjakan mikroskopik yang penting bagi pengukuran ramalan faktor pemulihan minyak dalam medan minyak, terutamanya dalam reserbor yang sangat telap.

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LIST OF SYMBOLS

%	-	percentage
°F	-	degree Fahrenheit
μ_o	-	Viscosity of oil
μ_w	-	Viscosity of water
API	-	American Petroleum Institute
CO_2	-	Carbon dioxide
EOR	-	Enhanced Oil Recovery
GOR	-	Gas-to-Oil Ratio
k	-	Permeability
k_o	-	Effective permeability of oil phase
k_{ro}	-	Oil relative permeability
M	-	Mobility
Md	-	milli-Darcy
PAG	-	Polymer Alternating Gas
RF	-	Recovery Factor
ROS	-	Residual oil saturation
S_o	-	Oil Saturation
S_w	-	Water Saturation
t	-	Time
WAG	-	Water Alternating Gas
wt %	-	weight percentage
λ	-	Mobility
μ	-	Viscosity
ϕ	-	Porosity

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CHAPTER 1

INTRODUCTION

1.1 Background of Study

Carbon dioxide has been used commercially to recover oil from reservoirs over 40 years. Presently, CO_2 flooding is the second most applied enhanced oil recovery (EOR) process in the world after steam flooding. Water alternating gas (WAG) or miscible CO_2-WAG injection has been a prevalent method to control mobility and enhance volumetric sweep efficiency for CO_2 flooding. Typical EOR is about 9.7% with a range between 6 and 20% for miscible WAG injection. Despite the success of WAG injection, sweeping efficiency is a typical challenge to achieve higher oil recovery during CO_2 flooding.

Almost all commercial miscible gas injection projects use WAG to control mobility of gas and lessen fingering problems. Recovery of WAG is better compared to gas injection alone, and 80% of commercial WAG projects in the US are cost-effective (Christensen, Stenby and Skauge, 1998). Recent studies however, show that most fields were unable to achieve the expected recovery factor from the WAG process, especially for high-permeability reservoirs (Christensen, Stenby and Skauge, 2001).

A new combination method was proposed to overcome the problems of gas breakthroughs and gravity segregation, just like during the WAG. This new method, called polymer alternating gas (PAG), combines the elements of CO_2 flooding with polymer flooding to make the WAG flood chemically improved. Polymers coupled with CO_2 are expected to enhance the efficiency of the current WAG. The main feature of PAG is that water is injected into the polymer during the entire WAG process. Polymer injection chased with gas alternative water (PGAW) experiment based on Saskatchewan crude was conducted by Zhang, Huang and Luo (2010). They mentioned that the coupled CO_2 and polymer injection improved recovery and efficiency compared to WAG and polymer flooding. The first coupled CO_2 and polymer injection simulation study for light oil based on a synthetic and homogeneous model was conducted by Majidaie, Khanifar and Onur (2012). Their study showed that PAG and WAG have almost the same recovery. Successful PAG and WAG application requires a good understanding of conformance, mobility and areal and vertical sweep efficiencies.

1.2 Problem Statement

Traditional gas (CO_2) flood methods suffer from insufficient sweep efficiency and incomplete recovery of oil. Caudle and Dyes (1958) observed that the sweep efficiency of a gas injection process can be enhanced by reducing the mobility behind the flooding front. This is achieved through the injection of a water slug and a gas slug. The water slug can reduce relative gas permeability and thus reduce the total mobility of the gas. The miscible slug is driven by a simultaneous injection of water and gas into the correct ratio in their proposed method. This method is changed to the Water Alternating Gas (WAG) process to prevent injectivity problems and other operational limitations associated with simultaneous injection.

During the WAG process, short slugs of gas and water are alternately injected to reduce the residual oil saturation and to control the mobility of gas. The recovery is better than water and gas injection alone (Rogers and Grigg, 2000) because the higher macroscopic efficiency of water merges with the higher microscopic efficiency of gas, giving a better oil recovery (Poollen, 1980; Christensen *et al*, 2001; Crogh *et al*, 2002; Awan *et al*, 2008). WAG has been widely used to improve the areal and vertical sweep efficiencies of gas/CO_2 flood (Kane, 1979; Champion and Shelden, 1989). WAG improves the recovery and the use of gas/CO_2 because the water injected has a higher viscosity than gas, which provides a better conformance control.

Although the WAG process is theoretically sound, its field incremental recovery is unsatisfactory because it seldom exceeds 5 to 10 % OOIP. Recent studies have shown that most of the fields were unable to reach the expected recovery factor from WAG processes (Sharma and Rao, 2008). Christensen *et al* (2001) have reported that the average recovery factor in immiscible WAG is 6.4 percent and in miscible case it is around 9.7 percent. Some studies also show that WAG occasionally has problems with high permeability zone channelling (Christensen *et al*, 2001; Chen et al, 2010). This is because the mobility ratio between the displacement and the displaced phases is not sufficiently reduced. In addition to operational problems, the WAG mechanism has inherent challenges such as gravity segregation water blocking, high viscosity oil mobility control, and reduced relative permeability of the oil and reduced injectivity of gas.

In this study, the above-mentioned WAG problems are addressed by adding polymer to the WAG cycle to further increase water viscosity and reduce the mobility ratio in order to reduce channelling and improve oil recovery. Polymer alternating gas (PAG) is therefore proposed to improve the efficiency of sweeping and recovery of oil. There have been a number of PAG research studies (Zhang *et al*, 2010; Li and Schechter, 2014; Li *et al*, 2014). Li *et al*, (2014) carried out a PAG simulation study using ECLIPSE for a highly heterogeneous North Burbank Unit field in Osage County, Oklahoma. Their study showed that the optimized PAG could increase oil recovery by approximately 14.3 percent compared with WAG by 7.3 percent. These studies have shown the potential benefit of polymer and CO_2 synergies. Hence, in the present work, a simulation study using reservoir simulator called STARS® commercialized by Computer Modelling Group Ltd. (CMG) is conducted to investigate the potential benefit of adding polymer to the water during CO_2 WAG process by taking the advantage of polymer conformance control during water cycle and CO_2 miscibility with oil. Each EOR method's performance on incremental oil recovery is also evaluated, including the water flood, CO_2 (gas) flood, water alternating gas (WAG), polymer flood and polymer alternating gas (PAG). The effect of each flooding method on residual oil saturation and sweep efficiency is also addressed.

1.3 Objectives of the Study

The objectives of this study are:

1. To compare the incremental oil recovery factor between PAG flooding, polymer flooding, miscible CO_2-WAG flooding, gas flooding and water flooding.
2. To visualize and evaluate the areal sweep efficiency of polymer flooding.
3. To evaluate and compare the effect of each EOR method on the residual oil saturation.
4. To evaluate the potential of PAG as a secondary or tertiary enhanced oil recovery mechanisms in a synthetic sandstone reservoir.

1.4 Scopes of Study

In order to achieve the objectives, the following scopes are drawn:

1. The study is done in a simulator developed by the Computer Modelling Group (CMG) known as STARS, Thermal & Advanced Processes Reservoir Simulator.
2. STARS is a thermal, k-value compositional, chemical reaction and geomechanics reservoir simulator in which one can perform advanced modelling of EOR processes such as polymer.
3. Options available for polymer flooding in STARS are studied.
4. The synthetic sandstone reservoir is constructed using CMG Builder.
5. The study is conducted in a homogeneous oil reservoir.
6. The optimum water injection rate is 1,200 STB/day
7. The optimum gas injection rate is 2052.94 MSCF/day.
8. WAG cycle time is 4 months. (2 months of CO_2 injection, followed by 2 months of water injection)
9. WAG ratio is 1:2 (50% time of CO_2 is injected and 50% of time water is injected)
10. Both production and injector well are vertical wells.

1.5 Significance of Study

This study is vital to solve problems related to Water Alternating Gas (WAG) such as early gas breakthrough and poor sweep efficiency by using PAG flooding. Polymers act essentially to increase the viscosity of the water injected and to reduce the permeability of the swept zone, to increase the vertical and areal sweeping efficiency of the water injection and thus to increase the recovery of the oil. Only few polymer and gas flooding studies using CMG-STARS have been published (Li and Schechter, 2014). Therefore, it is the interest of this study to investigate the feasibility of PAG flooding compared to other EOR methods in order to be implemented in Malaysian oilfields.

1.6 Thesis Outline

This thesis basically comprises of five main chapters. The first chapter explains the introduction of the project work. The second chapter describes all the related literature reviews pertaining to the project. The third one explains the methodology of the project and the fourth chapter carries the results for this study backed up by relevant references in the literature. The last chapter concludes the project.

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